Expre s Mail Lab l No.: EV 051923534 US
Date Mailed: July 25, 2003

UNITED STATES PATENT APPLICATION FOR GRANT OF LETTERS PATENT

Douglas K. Lawson
INVENTOR

Deburring Tool

COATS & BENNETT, P.L.L.C.
P.O. Box 5
Raleigh, NC 27602
(919) 854-1844

DEBURRING TOOL

FIELD OF THE INVENTION

The present invention relates to deburring tools, and more particularly to a robotic deburring tool.

BACKGROUND OF THE INVENTION

It is common to program robots to perform routine and repetitive tasks in manufacturing. One such task is the deburring of the edges of machined or cast parts. A robotic arm may be fitted with a deburring tool and programmed to follow a path around the edge of a particular part or object which is to be deburred.

There are some difficulties normally associated with the use of robotically controlled deburring tools. Since the programmed path of the robotic arm is in essence a series of incremental steps, the path of the robotically controlled deburring tool does not exactly coincide with the shape or contours of the surface to be deburred. In addition, the edge or surface may have cavities within the surface or even protrusions, sometimes prevalent in castings, extending from the surface to be deburred. These pockets and protrusions interfere with the path and cutting force of the robotic tool. A protrusion will urge the cutting surface of the deburring tool out of its programmed path and cause a consequent increase in cutting force. The increased cutting force may cause the deburring tool to cut too deep into the surface. Moreover, the increased cutting force may cause damage to the cutting surface of the tool. A cavity on the other hand may cause the deburring tool to separate or diverge from the surface to be machined. The separation of the cutting surface of the tool from the surface to be deburred will prevent the deburring of that portion of the part or workpiece. Consequently, the overall quality of the product being deburred will be affected.

In addition to part variations, there are fixture variations. Fixtures are structures that hold the parts while the parts are being subjected to deburring. Fixtures are designed to hold the parts such that the surface to be deburred aligns with the programmed path of the deburring tool. However, typically, these fixtures will have variations, and the variations will result in the surfaces of the parts to be deburred being misaligned with the programmed path of the deburring tool.

Traditionally, these problems have been dealt with by designing expensive and complicated active compliance whereby sophisticated electronic controls manipulate the robotic arm. Compliance compensates for errors in the path and variations in parts and fixtures by permitting limited movement of the tool while maintaining an acceptable cutting force. In this way, variations in the surface being deburred or inaccuracies in the programmed path which are within the limits of the compliance will be accommodated and damage to the cutting surface of the tool and the finished product will be minimized.

Several types of compliant tool holders have been disclosed in the prior art. In U.S. Patent No. 4,637,775 entitled "Industrial Robot Device," compliance is provided by a spring built into the device holding the tool. The spring permits the tool, which is comprised of the cutting surface and the drive means for the cutting surface, to move laterally relative to the axis of the tool and away from the edge being deburred. In U.S. Patent No. 4,860,500 entitled "Passive Actuator to Maintain a Constant Normal Cutting Force During Robotic Deburring," an air cylinder with a low friction piston is used to provide a zero spring rate compliance. Here the cutting surface and the drive means of the tool are permitted to move laterally to accommodate path errors and surface variations. Further, it is known to provide compliance devices in robotic deburring tools. For example, there is commercially available a robotic deburring tool known as *Amtru Flexicut 240* which is manufactured in Switzerland. This robotic deburring tool includes an air motor disposed within a housing. The air motor includes a rear or back portion

that lies within a ring-type compliance device while the front portion of the air motor extends through a mounting structure that permits the front portion of the motor to pivot. The pneumatic motor in the Amtru Flexicut deburring tool is relatively large, and because of that the entire tool is relatively heavy, bulky and expensive.

SUMMARY OF THE INVENTION

The present invention entails a deburring tool having a housing and a pneumatic motor mounted in the housing. The pneumatic motor includes a spindle and a backwall. A pivot-bearing is mounted adjacent the backwall of the pneumatic motor. A connector extends from the backwall of the pneumatic motor and connects to the pivot bearing. This permits the pneumatic motor to move with the pivot bearing. A compliance device extends around the pneumatic motor at a location between the backwall and an outer end of the drive shaft. The compliance device limits the movement of the pneumatic motor and applies a compliance force to the pneumatic motor as the pneumatic motor moves with the pivot bearing.

In another embodiment of the present invention, the deburring tool includes a housing and a pneumatic motor mounted in the housing and which includes a back portion and a front portion. A pivot bearing is mounted adjacent the back portion of the pneumatic motor. A connector extends from the back portion of the pneumatic motor to the pivot bearing and connects the pneumatic motor with the pivot bearing such that the pneumatic motor may move with the pivot bearing.

In yet another embodiment of the present invention, the deburring tool comprises a housing and a pneumatic motor mounted in the housing. The pneumatic motor includes a back portion and a front portion and wherein the back portion includes a cross-sectional area greater than the cross-sectional area of the front portion. A mounting structure is disposed at least partially within the housing for moveably

mounting the pneumatic motor therein. A compliance device extends around the front portion of the pneumatic motor for restricting the movement of the pneumatic motor and applying a compliance force to the pneumatic motor.

Other objects and advantages of the present invention will become apparent and obvious from a study of the following description and the accompanying drawings which are merely illustrative of such invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a perspective view of the deburring tool.

Figure 2 is an exploded perspective view of the deburring tool.

Figure 3 is a longitudinal sectional view of the deburring tool taken through the line 3-3 of Figure 1.

Figure 4 is an enlarged sectional view of a portion of the deburring tool illustrating how the rear portion of the pneumatic motor is moveably mounted within the housing.

Figure 5 is a perspective view of the compliance device of the deburring tool.

Figure 6 is a sectional view of the compliance device illustrating the compliance device set-up for operation in one mode.

Figure 7 is an enlarged sectional view of a portion of the compliance device shown in figure 6.

Figure 8 is a sectional view of the compliance device set-up for operation in a second mode.

Figure 9 is an enlarged sectional view of a portion of the compliance device shown in figure 8.

Figure 10 is a fragmentary sectional view of the deburring tool illustrating the manner of directing compressed air to the compliance device.

DESCRIPTION OF EXEMPLARY EMBODIMENT

With further reference to the drawings, the deburring tool of the present invention is shown therein and indicated generally by the numeral **10**. Deburring tool **10** includes a housing **12**. Mounted within the housing is a pneumatic motor **14**. Pneumatic motor **14** is supported within the housing **12** by a bearing assembly 16 and a compliance device **20**. More particularly, a pivot bearing **16** is secured within the rear of housing **12** and is operatively connected to the back of pneumatic motor **14** through a connector indicated generally by the numeral **18**. Pneumatic motor **14** is effectively suspended or supported at the rear by the pivot bearing **16**. A front or spindle portion of the pneumatic motor **14** projects through the compliance device **20**. As will be appreciated from subsequent portions of the disclosure, the pivot bearing **16** enables the pneumatic motor **14** to freely articulate radially in any direction while preventing free rotation about the bearing's longitudinal axis. Compliance device **20**, which surrounds the spindle or front portion of the pneumatic motor **14**, functions to center the spindle of the pneumatic motor **14**, but also yields in response to a disturbing force experienced by the deburring tool **10**.

Turning first to a discussion of the housing **12**, it is seen from Figures 1-3 that the housing includes a cylindrical section **30**. The cylindrical section includes a series of openings **32**. Some of the openings **32** function to exhaust air utilized by the pneumatic motor **14** while another opening provides access for an air inlet through which compressed air passes for the purpose of driving the pneumatic motor **14**.

As seen in the drawings, opposite ends of the cylindrical section **30** are open. Secured to the rear portion of the cylindrical section **30** is a back plate **34**. Back plate **34** includes a central opening **36** formed therein. Formed about the outer circumference of the back plate **34** is an air inlet **38**. As will be discussed in further detail subsequently

herein, compressed air is directed through the air inlet **38** and to the compliance device **20** which is mounted in the front portion of the housing **12**.

Formed about the circumference of the back plate **34** is a series of through bores. A series of screws **40** project into these through bores and into threaded openings formed around the back edge of the cylindrical section **30**. Consequently the screws **40** effectively secure the back plate **34** to the central section **30**. Opposite the back plate **34** is a front opening **42** which can be seen in Figure 2. Spaced inwardly from the front opening is a circumferential shoulder **44**. Again, as will be understood from subsequent portions of this disclosure, shoulder **44** serves as a stop against which the compliance device **20** rests when the compliance device is appropriately secured within housing **12**.

As noted above, the pneumatic motor **14** is housed within housing **12**. Various types of pneumatic motors can be utilized. In one exemplary embodiment, a pneumatic motor of an air turbine type rated at 340 watts and 40,000 rpm would be appropriate. In the case of the pneumatic motor **14**, particularly shown in Figures 2 and 3, for purposes of reference, the pneumatic motor **14** includes a rear portion **80** and a front or spindle portion **82**. As illustrated in Figures 2 and 3, note how the rear portion **80** tapers down and transitions into the front or spindle portion **82**. The rear or back portion **80** is of a cross-sectional area greater than the front or spindle portion **82**. By the same token, the rear portion **80** is more massive than the front portion **82**. Consequently, the center of gravity of the motor **14** tends to reside in or near the rear portion **80**.

Front or spindle portion **82** would include a drive shaft **86** that extends through the front or spindle portion and is operative to drive a collet **90**. Secured to collet **90** in a conventional fashion is a cutter or deburring tool **92**.

Pneumatic motor **14** includes a housing **88** and forming a portion of the housing is a back or back wall **84**. Back **84** includes a threaded opening formed therein. As will

be discussed later, the threaded opening receives and supports a connector that projects therefrom and which connects to the bearing assembly **16** which effectively supports the rear portion of the pneumatic motor **14**.

Mounted within end plate **34** is the bearing assembly indicated generally by the numeral **16** and sometimes referred to as a pivot bearing. The bearing assembly includes an outer race or socket **100**. Secured within the outer race **100** is a bearing **102**. In the case of the embodiment illustrated herein and particularly shown in Figures 2-4, the bearing **102** includes an arcuate shaped outer surface that freely moves within the race **100**. Bearing **102**, in the embodiment illustrated, assumes a partial ball or spherical configuration and includes a through bore or opening that extends through the same. Note in Figure 4 where the end plate **34** includes a circumferential shoulder **104** that extends around a portion of the opening **36** formed therein. Formed in the end plate adjacent the shoulder **104** is a series of threaded openings that are adapted to receive a series of screws **106**. Note that each screw **106** includes a head portion. To secure the bearing assembly **16** within the end plate **34**, the respective screws **106** effectively pinch the outer race or socket **100** of the bearing assembly **16** between the head of the screws **106** and the circumferential shoulder **104**. This is best illustrated in Figure 4.

Bearing **102** is designed to freely move radially in all directions but prevented from free rotation. To achieve this, a slot **108** is formed in an outer portion of the bearing **102**. Again, this is illustrated in Figure 4. A dowel pin **110** is inserted through the outer race **100** into the slot **108**. The dowel pin is fixed with respect to the outer race **100**. Thus the bearing **102** can pivot within the outer race **100** about the axis of the dowel pin **100**. Further, the bearing **102** can rock back and forth or from left to right as viewed in Figure 4. That is, the bearing **102** may move such that the slot **108** formed therein moves back and forth about the dowel pin **110**. Consequently, this gives rise to the bearing having the capability to move or pivot. However, the dowel pin **110** and the slot

108 prevent the bearing **102** from rotating about the longitudinal axis of the race **100** of the bearing.

Extending from the pneumatic motor **14** into the bearing assembly **16** is a connector indicated generally by the numeral **18**. The connection **18** may be a part of the pneumatic motor **14** or may be a separate component. As noted above, formed in the back **84** of the pneumatic motor **14** is a threaded bore. Secured within the threaded bore is a stud **120**. See Figures 2-4. Stud **120** projects rearwardly from the back **84** of the motor **14**. Forming a part of the stud **120** is a series of expandable threaded sections **120A**. See Figures 2 and 4. The expandable sections **120A** project through the opening within bearing **102**. To secure the connector **18** and particularly stud **20** within the opening within bearing **102**, there is provided a tapered threaded plug **122**. Threaded plug **122** is screwed into the opening formed within the expandable sections **120A**. As the threaded plug **122** is advanced, the sections **120A** of the stud expand and engage the bearing **102**. As the plug **122** is advanced towards the pneumatic motor **14**, the expandable sections **120A** continue to be expanded and a resulting outward directed force causes the expandable sections **120A** to be securely stationed within the internal opening within the bearing **102**.

Mounted in the front portion of the housing **12** is the compliance device **20**. Compliance device **20** is particularly illustrated in Figures 5-7. Compliance device **20** assumes a ring configuration and is adapted to extend around the front or spindle portion **82** of the pneumatic motor **14** when mounted within the housing **12**. With particular reference to Figure 5, the compliance device **20** is shown therein and includes two sides **152** and **154**. When mounted within the housing **12**, side **152** forms a front side while side **154** forms a rear side and faces back towards the rear portion **80** of the pneumatic motor **14**. Formed within the compliance device **20** is an opening **156**. Opening **156** is defined by a circumferential surface **156A**. Extending around the outer

edge of the compliance device **20** is a circumferential edge **158**. Formed about circumferential edge **158** is a pair of spaced apart O-ring seats **158A** and **158B**. When mounted within the housing **12**, a pair of O-ring seals **168** are seated within seats **158A** and **158B**.

Formed in the compliance device **20** is a series of spaced apart piston assemblies. Each piston assembly is formed by a bore **160**. Note that each bore **160** extends from the circumferential edge **158** inwardly to the central opening **156**. A bushing **162** is pressed into each bore **160**. This is illustrated in Figures 7 and 9. Reciprocally mounted in the bushing **162** is a piston indicated by the numeral **164**. Piston **164** includes a base **164A** and a seal seat **164B** that extends around base **164A**. As will be explained later, the compliance device **20** is adapted to operate in two different modes, one mode with seals and one mode without seals. Figure 7 illustrates the mode where the respective pistons **164** are provided with seals. More particularly, there is provided a seal **164C** that is seated within seal seat **164B**. Extending inwardly through the bore **160** is a rod or pin **164D**. Rod or pin **164D** includes a generally arcuate or rounded outer tip.

As is appreciated, compliance device **20** is operated by fluid. In the case of one embodiment, compressed air is utilized to actuate and bias the pistons towards an extended position (shown in Figures 7 and 9) within opening **156**. Consequently, it is important to provide compressed air between the circumferential edge **158** and the central section **30** of the housing **12**. Therefore, an air channel **256** is provided within the outer ring of the compliance device **20**. More particularly, the air channel **256** includes an inlet end formed on the rear side **154**. The air channel extends therefrom a predetermined distance and then turns approximately 90° where the same air channel terminates about the circumferential edge **158**. See Figure 5. Thus, air can be directed into an opening or port formed on the rear side **154** of the compliance device and

through the air channel **256** to where the air is exhausted out the circumferential edge **158**. From there the air can move around the circumferential edge **158** and into the various bores **160** formed in the ring portion of the compliance device **20**.

To retain the air about the circumferential edge **158** of the compliance device **20**, there is provided a pair of O-rings **168**. This is particularly illustrated in Figures 7 and 9 as well as Figure 3.

Formed about the front portion of the central opening **156** is a relatively soft O-ring buffer **170**. As will be appreciated from subsequent portions of the disclosure, a sleeve extends around the front or spindle portion **82** of the pneumatic motor **14** and as the front or spindle portion **82** moves back and forth, the buffer **170** functions to engage and soften the impact of the spindle **82**.

To facilitate mounting and aligning the compliance device **20** in the front portion of the housing **12**, there is provided at least one bore **172** that is formed on the rear face **154** of the compliance device. One or more pins **174** project from the shoulder **44** into the one or more pin bores **172**. A snap ring **176** is snapped into a groove in the front of the central section **30** of the housing **12**. Snap ring **176** abuts against the front face **152** of the compliance device **20** and holds the same within the front portion of the housing. Note that the shoulder **44** formed in the front portion of the housing **12** acts as a stop against which the back side **154** abuts when the compliance device **20** is mounted within the housing. Therefore, the compliance device is securely held in place within the housing **12** by the shoulder **44** and the snap ring **176**.

Secured on the front portion or spindle **82** of pneumatic motor **14** is a contact sleeve **200**. Contact sleeve **200** is particularly spaced on the spindle **82** such that it aligns with the pistons **164** disposed within the compliance device **20**. This is particularly illustrated in Figure 3. Formed on the inside surface of the contact sleeve about a front portion is an O-ring seat. An O-ring **202** is secured within the seat and acts as an

interface between the contact sleeve **200** and the adjacent spindle **82**. In addition, the contact sleeve **200** is firmly fixed about the spindle **82** by a retaining ring **204**. As illustrated in Figure 2, retaining ring **204** is designed to fit over the spindle **82** and to securely lock the contact sleeve **200** in a position on the spindle **82** where the compliance device surrounds the contact sleeve. Therefore, it is appreciated that when a compliance force is exerted on the pneumatic motor **14** by the compliance device **20**, that the pistons **164** of the compliance device will actually engage the outer surface of the contact sleeve **200**.

The front portion of the deburring tool **10** is closed by a boot **206** and a boot retaining ring **208**. More particularly, boot **206** is slipped or past over the spindle **82** of the pneumatic motor **14** and secured around the front face or side **152** of the compliance device **20** by the boot retaining ring **208**. A set of screws **210**, as illustrated in Figures 2 and 3, are extended through openings within the boot retaining ring **208** and further through the openings within the boot **206** and screwed into the threaded bores **178** formed on the face **152** of the compliance device **20**.

In a preferred embodiment, the power source for driving the deburring tool **10** is a pneumatic type motor. To supply air to the pneumatic motor **14** there is provided an air inlet fitting **230**. See Figures 1-3. Air inlet **230** is of an L-shaped design and is directed to the pneumatic motor **14** through an opening in the central section **30** of the housing **12**. Note that a portion of the air inlet **230** is directed through a boot **232** and a retaining ring to where the air inlet connects to an opening in the pneumatic motor **14**. Boot **232** is held within the opening within central section **30** by the retaining ring **234**. In operation, a source of compressed air is connected to the air inlet **230** and supplies air to the pneumatic motor **14**.

Another air inlet, air inlet **250** is also provided. Air inlet **250** is secured to port **38** formed in the end plate **34**. Air inlet **250** is utilized to direct air into the deburring tool **10**

that is ultimately used to drive or power the compliance device **20**. In order to route compressed air from the air inlet **250** to the compliance device **20**, there is provided a series of air channels or conduits formed in the housing **12**. See Figure 10. In this regard, there is an air channel **252** that extends from port **38** in the end plate **34**. In addition, another air channel **254** extends through the wall of central section **30** and connects air channel **252** with air channel **256** formed in the compliance device **20**. As seen in Figure 10, the air channel **256** formed in the compliance device **20** extends inwardly from the rear side **154** a predetermined distance and then turns outwardly and extends towards the outer circumferential edge **158** of the compliance device where the air channel terminates.

It is appreciated that when the end plate **34** is secured to the central section **30** of the housing and the compliance device **20** is properly secured within the housing **12**, that the air channels **252**, **254** and **256** will align. In addition, there will be provided O-rings between the respective air channels so as to prevent air from significantly leaking as the air moves from the end plate **34** to the compliance device **20**.

Compliance device **20** functions to center the spindle or front portion **82** of the pneumatic motor during operation. However, the compliance device is yieldable. That is, when a disturbing force is encountered by the deburring tool **92**, the spindle **82** will be caused to move and one or more pistons mounted within the compliance device **20** will be engaged by the spindle **82** and because of the disturbing force, the respective pistons **164** will yield and retract within the bores **160** of the compliance device **20**. As the robotic tool moves around the surface being deburred, the disturbing force will subside, and the pneumatic pressure acting on the pistons **164** will urge the spindle **82** to a centered position. Because of the constant pneumatic pressure being applied to the base **164A** of the pistons, the tendency of the compliance device is, of course, to maintain the spindle **62** in a centered position as illustrated in Figure 3.

As illustrated in Figures 6-9, the respective pistons **164** have a limited inward extension. In Figures 7 and 9 the pistons **164** are fully extended inwardly. Note that the base **164** abuts against the bushing **162**. This assures that the pistons **164** can only be extended inwardly a predetermined distance.

One feature of the deburring tool **10** of the present invention is that the deburring tool can provide a variable compliance force. This is particularly illustrated in Figures 7 and 9. That is, in one mode of operation deburring tool **10** may provide a greater compliance force than in a second mode of operation. This is achieved by electing on the one hand to utilize the seals **164C** or electing not to use the seals. In Figure 7, for example, the deburring tool **10** has been set up in a mode of operation that utilizes seals **164C** around the base **164A** of each piston **164**. As illustrated in Figure 7, the effective area subjected to the compressed air is illustrated by the letter **X**. To reduce the compliance force being exerted by the compressed air on the pistons, the seals **164C** can be removed. This is illustrated in Figure 9. Here note that there are no seals extending around the seal seat **164B**. In this case, as illustrated in Figure 9, the effective area acted on by the compressed air is illustrated by the letter **Y**.

In the case of the design illustrated herein, the pneumatic motor **14** includes a varying cross sectional area from back to front. As seen in the drawings, the back or rear portion **80** of the pneumatic motor **14** is larger than the front or spindle portion **82**. This means that the back portion **80** would weigh more than the front portion **82** and consequently the center of gravity of the motor **14** would tend to be located more towards the rear or back portion of the motor than towards the front portion of the motor. Accordingly, the present invention has placed the primary mounting structure for the pneumatic motor **14** adjacent the rear portion **80**. In this regard, as discussed above, the bearing assembly **16** is disposed adjacent the back wall **84** of the motor. The arrangement of the bearing assembly **16** and the connector **18** permits the motor **14** to

swivel or pivot about the outer race **100** of the bearing **16**. In the case of the particular embodiment illustrated herein, the motor **16** can move or pivot radially similar to a joystick. Other types of mounting arrangement could be utilized.

The deburring tool **10** of the present invention has many advantages. Because of the design and arrangement of the motor **14**, compliance device **20** and the manner of movably mounting the motor **14** within the housing **12**, the overall deburring tool is relatively small, of a light weight, and inexpensive.

The present invention may, of course, be carried out in other specific ways than those herein set forth without departing from the scope and the essential characteristics of the invention. The present embodiments are therefore to be construed in all aspects as illustrative and not restrictive and all changes coming within the meaning and equivalency range of the appended claims are intended to be embraced therein.